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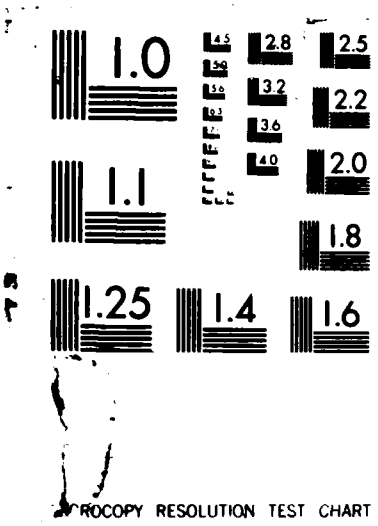
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INCREASES IN ALDOSTERONE PRECEDE THOSE OF CORTISOL DURING GRADED EXERCISE

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INCREASES IN ALDOSTERONE PRECEDE THOSE OF CORTISOL DURING GRADED EXERCISE

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SUMMARY

Aldosterone and cortisol are the two major hormones secreted by the human adrenal cortex. Exercise is one of the stresses known to increase the levels of both of these hormones, although the intensity of exercise needed to elicit secretion is different for the two. The purpose of this study was to determine the intensity threshold needed to elicit increases in plasma levels of aldosterone and cortisol during graded exercise in humans.

Seven male volunteers (mean age = 27 years, height = 173 cm, weight = 72 kg, maximum oxygen uptake = 48 ml/kg/min) performed an incremental load cycle ergometer test to exhaustion. Aldosterone, cortisol, angiotensin II, ACTH and potassium were measured at rest and at the last two minutes of each 50 watt workload of the exercise test.

Aldosterone increased from 231 p mol/L at rest to 464 p mol/L at exhaustion. Cortisol increased from 284 n mol/L at rest to 311 n mol/L at exhaustion. However, aldosterone was increased at exercise intensities greater than 60% VO2 max while cortisol was only increased above the resting level at exhaustion.

Both potassium and angiotensin II were significantly correlated with aldosterone during exercise, which suggests that both are important stimuli for aldosterone secretion during graded exercise.

Aldosterone and cortisol were both increased by graded exercise to exhaustion. Aldosterone was increased at exercise intensities greater than 60% VO2 max. The increase in aldosterone preceded cortisol increase, a finding which is consistent with other studies of stimulus-secretion coupling in the adrenal cortex.

INTRODUCTION

The two major hormones secreted by the human adrenal cortex are the mineralocorticoid, aldosterone and the glucocorticoid, cortisol. Secretion of both of these steroid hormones is known to increase under stressful conditions such as surgery, hemorrhage, and physical exertion (Ganong, 1985). Although exercise is known to increase the plasma levels of both aldosterone and cortisol, it has recently been suggested that the intensity of exercise necessary to elicit secretion is different for the two hormones (Galbo, 1983). Support for such an assumption arises from the data of Few et al. (1980). In this study they reported that elevations in cortisol were significantly reduced during two-leg exercise as compared to one-leg exercise while aldosterone was not significantly different under the two-leg exercise condition. Furthermore, they found that aldosterone tended to increase before cortisol, particularly during the two-leg experiments. In light of the above data by Few et al. (1980), it was the purpose of this study to determine the intensity threshold needed to elicit increases in plasma levels of aldosterone and cortisol during graded exercise in humans.

METHODS

Seven male volunteers served as subjects for the study. The mean ($\pm$SE) age, height, weight and maximum O_2 uptake (VO_2 max) for the group was 26.7$\pm$1.0 yr, 173$\pm$4 cm, 72.1$\pm$3.2 kg, and 47.9$\pm$3.7 ml/kg/min, respectively. The subjects reported to the laboratory at least 4h postabsorptive after having refrained from exercise for at least 8h. Written informed consent was obtained from each subject prior to testing.

Each subject performed an incremental load VO_2 max exercise test on a Godart cycle ergometer. After resting measurements were collected, the initial load consisted of 2 min at 50 W. Thereafter the load was increased 50 W every 2 min until exhaustion. VO_2 was measured every min of the test using an automated sampling system (Alpha Technologies, System 4400, Laguna Hills, CA, USA).

Blood samples were collected at rest the last 15 s of each 2 min work-load and at exhaustion from an indwelling catheter (Travenol Laboratories, Deerfield, IL, USA) in a superficial forearm vein. The resting sample was

collected 30 min following insertion of the catheter. Approximately 10 ml of blood were withdrawn at each collection. The blood sample was immediately centrifuged, and the resulting plasma was frozen at -80°C.

All of the collected plasma samples were measured in duplicate for aldosterone, cortisol, ACTH, and angiotensin II using RIA procedures. The intra-assay coefficient of variation (CV) for each of the above hormones was less than 10%. Plasma potassium levels were measured via flame photometry and had a CV of 2%. All of the measured variables were analyzed using an analysis of variance for repeated measures and Dunnett's post-hoc comparisons. Significance was set at the $p \leq 0.05$ level.

RESULTS

The mean ($\pm$SE) cortisol and aldosterone responses to the graded exercise bout are presented in Figure 1. As can be seen, aldosterone increased from 231$\pm$22 p mol/L at rest to 464$\pm$22 p mol/L at exhaustion, or a mean 101% increase. Cortisol increased from 284$\pm$38 n mol/L at rest to 311$\pm$39 n mol/L at exhaustion, or a mean 10% increase. The magnitude of the increase in both hormones is comparable to previous studies (Maher et al., 1975; Maresh et al., 1985; White et al., 1976).

More importantly, however, is the fact that Figure 1 reveals that aldosterone was significantly increased above the resting level at exercise intensities $\geq$ 60% VO_2 max. Cortisol, on the other hand, was only significantly increased above the resting level at exhaustion (i.e., 100% VO_2 max).

The mean ($\pm$SE) angiotensin II, ACTH, and potassium responses to the graded exercise bout are presented in Figure 2. As can be seen, all three variables increased significantly as a result of the exercise bout. On a percentage basis the mean angiotensin II, ACTH, and potassium levels increased 336%, 314%, and 49%, respectively. Again, the magnitude of these increases are in agreement with previous studies (Fagard et al., 1985; Farrell et al., 1983; Laurell and Pernow, 1966).

DISCUSSION

The most important finding of the current study is that the exercise intensity necessary to elicit increases in aldosterone and cortisol appear to be different from each other. As can be seen in Figure 1, the plasma aldosterone level is increased much sooner (i.e., at a lower intensity) than cortisol during graded exercise. Such a result is consistent with the findings of Few et al. (1980) and would suggest that different stimuli are involved in aldosterone and cortisol secretion during exercise.

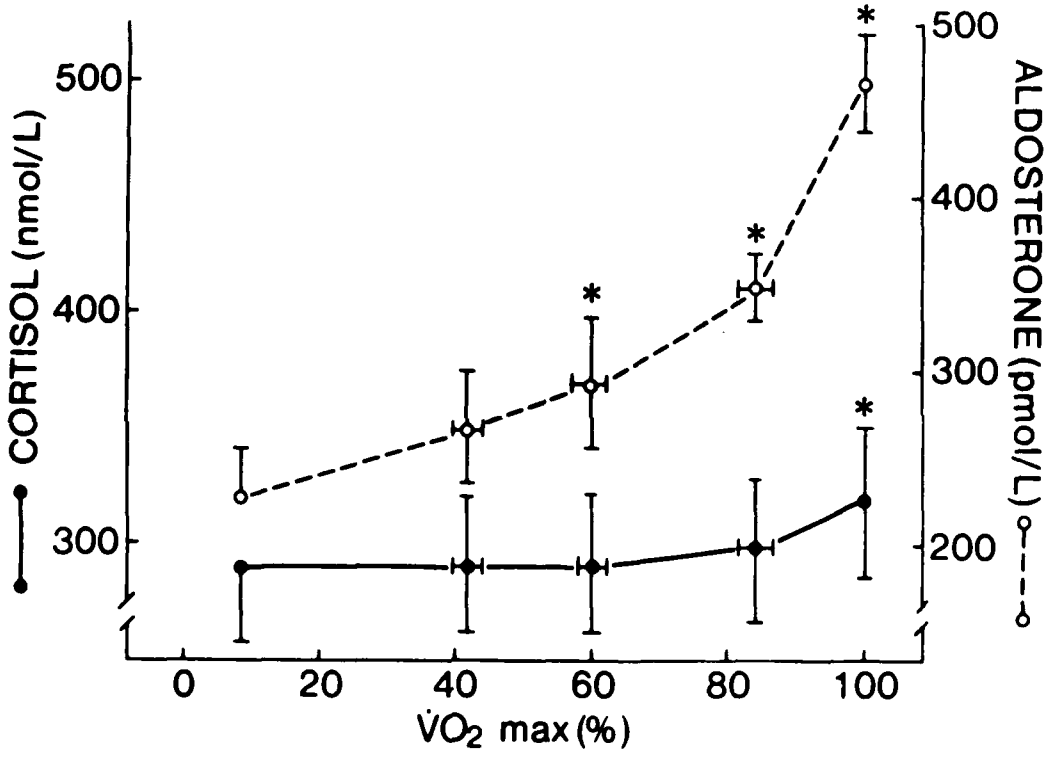

Figure 1: Mean (±SE) aldosterone and cortisol concentrations during graded execise. The first data point for each hormone is the resting value. n=7.

*Indicates that data point is significantly different ($p \geq 0.05$) from the resting value.

It is generally accepted that the two major stimuli for aldosterone secretion are increased plasma levels of angiotensin II and potassium (Ganong, 1985; Galbo, 1983; Viru, 1985). What is controversial, however, is the relative importance of the two stimuli in eliciting the increased aldosterone levels during exercise. For example, it has been shown by Kosunen and Parkarinen (1976) that following short-term, high intensity exercise, aldosterone and angiotensin II were strongly related. No relationship, however, was found between plasma potassium and changes in aldosterone. Therefore, the above data support the hypothesis that aldosterone secretion is predominantly under the renin-angiotensin system during graded exercise (Maher et al., 1975). On the other hand, Bonelli et al. (1977) found, following propranolol administration, that renin levels were suppressed during exercise but there was no significant difference in plasma aldosterone levels. These results would seem to suggest that hyperkalemia is the more important stimuli for aldosterone secretion during exercise.

The results of the current study (Figure 2) show that both angiotensin II and potassium increase during exercise. Furthermore, the time course of the exercise induced increases in angiotensin II and potassium are very similar to that of aldosterone (Figure 1). In fact, both potassium ($r=0.79$, $p<0.05$) and angiotensin II ($r=0.54$, $p<0.05$) were significantly correlated with aldosterone during exercise. The above findings seem to suggest that both variables are important stimuli for aldosterone secretion during graded exercise.

Previous studies (Galbo, 1983; Viru, 1985) have shown that exercise usually results in increased levels of both ACTH and cortisol. Furthermore, it is generally agreed that the increased cortisol secretion is the result of ACTH stimulation of the adrenal cortex (Ganong, 1985; Viru, 1985). The results of the current study seem to agree with the above cited works. For example, Figure 2 clearly shows that ACTH increases during exercise in an intensity dependent pattern and that significant increases are only achieved at exercise intensities $\geq$ 80% VO_2 max. Such a finding is consistent with the results of Farrell et al. (1983) who reported that ACTH levels were significantly increased following exercise at 80% and 100% VO_2 max but were

unchanged following exercise at 65% VO_2 max. Farrell et al. (1983) also reported that the 65% and 80% VO_2 max workbouts did not significantly increase cortisol levels but that exercise at 100% VO_2 max did.

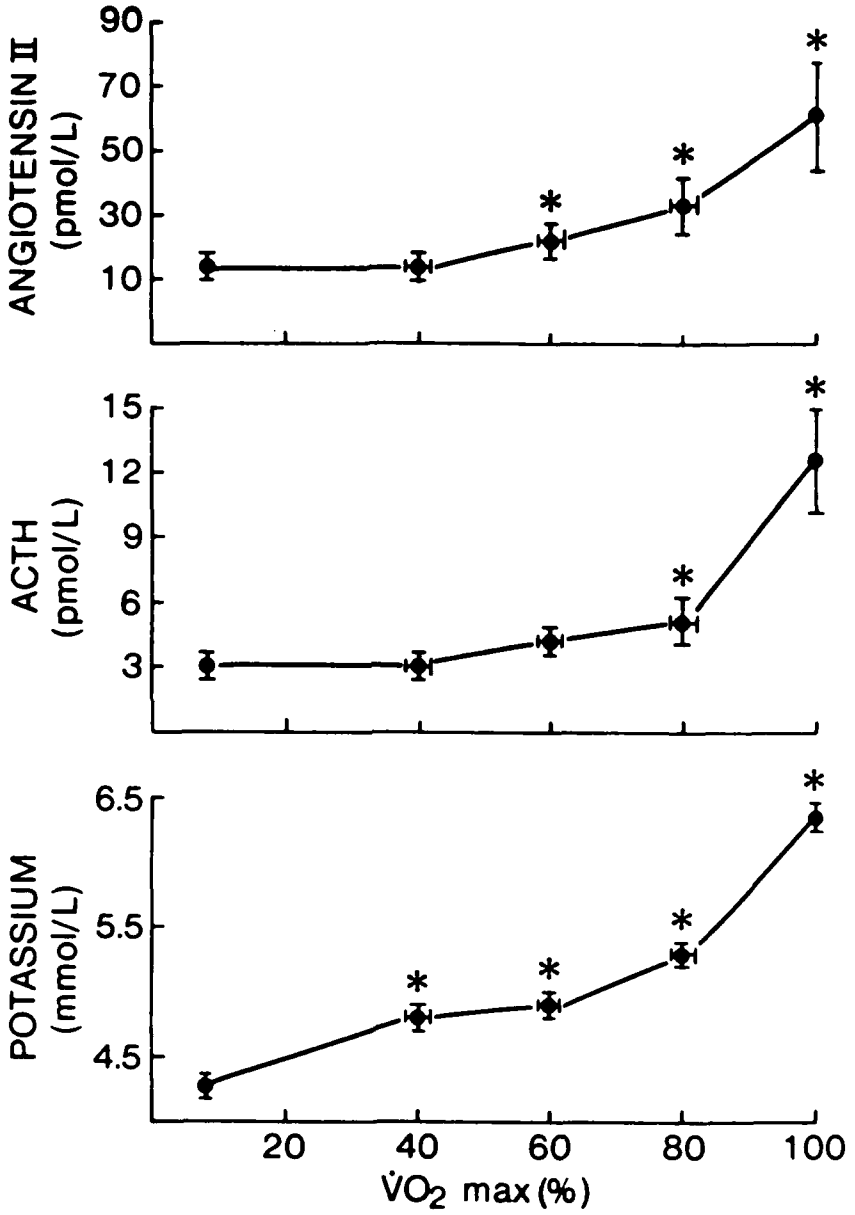

Figure 2: Mean (±SE) aldosterone II, ACTH, and potassium concentrations during graded exercise. The first data point for each variable is the resting value. n=7. *Indicates that data point is significantly different ($p \leq 0.05$) from the resting value.

The last point of interest was the fact that ACTH levels increased before cortisol levels during the graded exercise bout (Figures 1 and 2). Such a finding is consistent with numerous in vitro and in vivo studies that have examined stimulus-secretion coupling in the adrenal cortex (Brodish and Lymangrover, 1977). For example, Urquhart and Li (1968) showed, following a pulse injection of ACTH, the cortisol secretion rate began to increase following a 2 min delay. This stimulus-secretion delay can be accounted for by the fact that the adrenal cortex probably depends upon de novo systhesis rather than on stored cortisol for secretion (Sayers and Portanova, 1975).

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